Early Journal Content on JSTOR, Free to Anyone in the World

This article is one of nearly 500,000 scholarly works digitized and made freely available to everyone in the world by JSTOR.

Known as the Early Journal Content, this set of works include research articles, news, letters, and other writings published in more than 200 of the oldest leading academic journals. The works date from the mid-seventeenth to the early twentieth centuries.

We encourage people to read and share the Early Journal Content openly and to tell others that this resource exists. People may post this content online or redistribute in any way for non-commercial purposes.

Read more about Early Journal Content at http://about.jstor.org/participate-jstor/individuals/early-journal-content.

JSTOR is a digital library of academic journals, books, and primary source objects. JSTOR helps people discover, use, and build upon a wide range of content through a powerful research and teaching platform, and preserves this content for future generations. JSTOR is part of ITHAKA, a not-for-profit organization that also includes Ithaka S+R and Portico. For more information about JSTOR, please contact support@jstor.org.

NOTES ON RECENT DEVELOPMENTS IN CONCRETE[1]

By Lieut. Col. H. C. Boyden[2]

In 1914 the Structural Materials Research Laboratory was established at Lewis Institute, Chicago, with Prof. Duff A. Abrams at its head. The establishment of this laboratory was made possible through the coöperation of the Portland Cement Association and the Lewis Institute. This laboratory is a striking example of coöperation between an engineering college and a manufacturing industry of international scope.

There are only two ideas governing the policy of this laboratory; the first is, that the real facts regarding concrete and its ingredients shall be found out, with a liberal policy regarding the time required and the expense involved; the second is, that whatever the conclusions may be, they shall be given to the engineering profession for the improvement of the art of making concrete.

These investigations are still being carried on, but many points of vital importance have been established. As an example, the established data warrant the use of considerably higher unit stresses than those in common use today, with a consequent reduction in section.

Conclusions have also been arrived at that will enable us to obtain excellent results with aggregates heretofore condemned and to greatly increase the ability of concrete to resist wear.

These conclusions and many others, are all based on tests running into the thousands and covering long periods of time. The laboratory is equipped for and is making close to 50,000 tests a year, so that there is no lack of facilities for carrying out investigations in the most thorough manner.

The study of concrete may be conveniently divided into three phases:

1. The study of the characteristics of the ingredients.

[1] Presented by title at the Montreal Convention. Discussion is requested and should be sent to the Editor.

[2] With Portland Cement Association, 111 West Washington Street, Chicago.

2. The study of the effect of making various combinations of these ingredients.

3. The study of the effect of the various manipulations of the ingredients in making and curing the concrete.

It has been the custom to speak of concrete as having three ingredients, cement, fine aggregate and coarse aggregate. The laboratory studies have shown the desirability of classifying the ingredients as cement, aggregate and water, or if it is still desired to maintain the purely arbitrary division of the aggregate into fine and coarse, to add the fourth ingredient, water.

Although cement is one of the most important ingredients of concrete, it requires probably the least discussion, as all the standard brands of Portland cement on the market today conform to generally accepted specifications and the laboratory investigations have brought out no essential changes in these specifications.

As stated above, the aggregate has always been divided into two parts, sand and crushed stone or pebbles. The line of division, purely an arbitrary one, has been the quarter-inch screen; the portion passing through this screen has been classified as fine aggregate or sand, and that portion retained on the screen being called the coarse aggregate. There is no particular advantage gained by this division, but it would be much better to consider the aggregate as a whole, with a proper gradation of the various sizes from the largest to the smallest. It is not intended by this, however, to recommend the use of bank run or crusher run aggregate, as under no conditions should they be used without separating the sizes and recombining them in the proper proportions.

However, until such time as this method of considering the aggregate shall have become of general practice, it may be considered as divided into two parts by the $\frac{1}{4}$ inch or No. 4 screen, and the author will so discuss it.

Fine aggregate. It has been customary to specify that the fine aggregate shall be clean, sharp and not too fine. It would be better to use the word hard rather than sharp, as sharp sands give lower results than rounded or smooth sands. This is no doubt due to the larger amount of water required to obtain a workable mix when the sand is sharp or angular.

The laboratory studies have brought out two important facts regarding sands. One of these is the great importance of being sure that the material is clean, not only in appearance but in fact.

Very often sand which appears to the eye to be clean, contains enough humus or vegetable matter to reduce the strength of the concrete very considerably.

As an illustration a clean sand gave a compressive strength at 28 days of 1900 pounds. This same sand with one-tenth of one per cent of tannic acid added, gave a strength of only 1400 pounds; in other words, one-thousandth part of organic impurities in terms of the weight of the sand reduced the strength of the concrete nearly 25 per cent. In the investigation of the effect of organic impurities many natural sands were used, but as it was not feasible to secure sands containing a wide variation of organic impurities, tannic acid was used as a substitute for the purpose of making further tests. It was felt that the effect produced by such a material would probably be a measure of the effect produced by other organic impurities which might be present in natural sand.

How is it possible to detect these organic impurities if they cannot be seen by ordinary inspection? By using the colorimetric test for organic impurities devised at the laboratory. This test consists of digesting a representative sample of the sand in a dilute solution of sodium hydroxide (caustic soda = NaOH) and observing the resulting color of the liquid.

All that is needed is a 12-ounce prescription bottle and a little 3 per cent solution of caustic soda or sodium hydroxide, both obtainable at any drug store.

Put in about 4½ ounces of the sand to be tested, fill up to the 7-ounce mark, after shaking, with the solution of caustic soda, let it stand for 24 hours and observe the liquid on top. If this liquid is clear or light straw colored use the sand; if it runs into the brown color and especially dark brown, reject the sand or wash it thoroughly before using.

The second fact is that fine sand behaves exactly the same as coarse sand with one exception. In order to produce a plastic workable mixture with fine sand it is necessary to use more water than with a coarse sand. It is the excess of water that reduces the strength of the concrete. In other words if it were possible to mix concrete with the same quantity of water regardless of the grading of the sand, and obtain a plastic mix in both cases, the same strength in the concrete would be obtained.

Coarse aggregate. When studying the characteristics of the coarse aggregate one conclusion has been brought out very sharply;

namely, that the hardness of the aggregate is a secondary consideration as compared with other factors in developing high crushing strength in concrete, and of less importance than ordinarily supposed in developing wearing qualities. This was very clearly shown in comparative tests made of burnt shale for use in building concrete ships. Samples made with this aggregate compared very favorably with those made up using a much harder aggregate. A stone must be very friable indeed if it is not strong enough, when properly combined in concrete, to more than maintain the load likely to be carried by the concrete.

The reason for high compressive results given where a light, soft aggregate is used is because the water content is reduced, owing to the porosity of the aggregate and not due to a higher compressive strength in the aggregate. The water content is again found to be the governing factor.

For road surfaces, however, another quality is needed in concrete, namely, wearing or abrasive quality, and to obtain this the stone must not be too soft. It is not advisable to use a stone with a French coefficient of less than 7 although pavements have given excellent results made with stone having a coefficient as low as 6.

It is not intended in calling attention to the above results to advise throwing down the bars and allowing the use of any and all stones, irrespective of their hardness or wearing qualities. It is desired, however, to show that many of the safeguards put into specifications in past years are not safeguards at all but that the effect of following them may be entirely lost through neglect to observe other factors of more vital importance. It is always advisable to use the best materials obtainable but there have been many cases, where the local and easily obtained material has been rejected, when it could have been used with excellent results, by following proper principles in proportioning and protecting the concrete.

Oftentimes better results would have been obtained than resulted from the use of imported materials and then neglecting the really important factors in making good concrete.

Water. The remaining ingredient of concrete, water, is in reality of equal importance with the cement in obtaining good concrete, and yet it is often the most carelessly used and most loosely specified of all the ingredients, generally not mentioned in specifications and frequently not even reported in test data.

The laboratory is now conducting tests of waters sent in from all parts of the country, but definite conclusions have not as yet been developed. It is safe to say, however, that waters which are strongly alkaline should not be used and, owing to the possibility that marsh waters may contain sufficient humus matter to seriously affect the strength of concrete, they should be looked upon with suspicion until tested in concrete and found satisfactory.

With regards to the temperature of the mixing water, tests have been made using water ranging in temperature from 32° to 212° F. It was found that the temperature of the mixing water had very little to do with the strength of the concrete at seven days to one year. The use of hot water is, however, a valuable aid in removing frost from the aggregate in cold weather, owing to its high specific heat, and may be used without danger of harming the concrete.

Proportioning. It is on studying the second phase of concrete making, that there has been brought out at the laboratory new, and in some ways radical, changes in the past and present practices of proportioning.

These investigations have brought out the following facts: That the present method of designing concrete mixtures by using arbitrary volumes is wrong, that there is one single proportion which will give the best results with a certain mixture of given fine and coarse aggregates, adding to or reducing the amount of cement is of value only as it affects the amount of water required to make a workable plastic mixture and above all, that the water-ratio is the most important element of a concrete mix. The water-ratio is the ratio of the volume of water to the volume of cement in the batch. If 1 cubic foot of water (7.5 gallons) is used for each sack of cement, the water-ratio is 1.00.

The use of more cement in a batch does not produce any beneficial effect except from the fact that a plastic, workable mix can be produced with a lower water-ratio. The reason that a rich mixture gives a higher strength than a leaner one is not that more cement is used, but because the concrete can be mixed with a water-ratio which is relatively lower for the richer mixture than for the lean one. If advantage is not taken of this possibility of reducing the water-ratio the additional cement in the richer mixture is wasted.

Fineness-modulus. In studying the results of the tests of many samples of various combinations of aggregates it was evident that there must be some relation between the size and grading of the

aggregates and the strength of the concrete. In trying to find this relation Professor Abrams struck upon what is called the "fineness modulus" of aggregates and when this was compared with the strengths of the concretes a direct relation was found to exist.

The fineness modulus is a very simple function of the sieve analysis of the aggregate used for any particular concrete. The sand and stone are analyzed with a set of Tyler standard sieves, each one of which has a clear opening double the width of the next smaller. The following sizes are used: 100 mesh, 48 mesh, 28 mesh, 14 mesh, 8 mesh, 4 mesh, $\frac{3}{8}$ inch, $\frac{3}{4}$ inch and $1\frac{1}{2}$ inch. The percentages (by volume or by weight) of the total aggregate coarser than each sieve are added together, the sum of these percentages is divided by 100 and the result is the fineness modulus. The fineness modulus of any combination of the fine and coarse aggregates may be found in exactly the same manner.

It is not possible to go into the details of the use of this factor for the design of concrete mixtures in a talk of this length but they have been published in *Engineering News-Record* on April 17, 1919, and a careful study will enable one to use it successfully.

It is not claimed that this method of designing concrete mixtures is the only one that will give the desired results, but the laboratory tests prove beyond a doubt that there is a direct relation between the compressive strength of concrete and the factor called the "fineness modulus." Accepting this as a fact, it is possible to design a concrete mixture that will give a certain desired compressive strength from almost any combination of aggregates.

Abrams' tables of proportions. In order to make this more easily available to the engineers of the country Professor Abrams has worked out a table containing 135 proportions with different combinations of aggregates, which if used with materials acceptable as to quality, will give a concrete with a compressive strength at 28 days of approximately 3000 pounds per square inch. All the tests for the determination of the factors in this table were made of a concrete of a workable plasticity, formed into cylinders 6 by 12 inches and tested at the end of 28 days.

In conformity with present practice the aggregate is divided in the table into fine and coarse, and covers combinations of five classes of fine aggregates with twenty-seven classes of coarse aggregates.

In order to determine what class a known aggregate shall be placed in, the following rules should be followed; if a fine aggregate at least 15 per cent of the total shall be retained on the next smaller sized sieve, if a coarse aggregate at least 10 per cent shall be retained in the same manner.

This table shows a considerable reduction in the amount of cement required as compared with previously published tables especially when combined with the larger sizes of aggregates. As an illustration, the quantities used today for a 1:2:3 mix, with sand up to No. 4 and stone from No. 4 to $1\frac{1}{2}$ inch are 1.74 barrels cement, 0.52 cubic yard sand and 0.77 cubic yard of stone, while Professor Abrams' table calls for 1.61 barrels cement, 0.47 cubic yard sand and 0.72 cubic yard stone.

These figures are the exact quantities required for the making of one cubic yard of concrete and if used will effect a very material saving in the cost of the thousands of miles of concrete roads, pavements and other concrete structures to be built in the years to come.

An allowance for waste, varying for each ingredient and also according to the particular method employed in handling the work, should be added to the quantities given in the table. Professor Abrams is now preparing tables similar to the one already published, for concrete with a compressive strength of 2000 and 2500 pounds per square inch. As soon as these tables are completed they will be published in the technical press.

Water content. It is upon studying the water content that the most radical change from previous ideas on the design of concrete mixtures are found. It has been established that there is a direct connection between the amount of mixing water used and the strength of the concrete, and there is probably no other one factor which has so great an effect upon the strength as the water content.

It has been found that the less water used down to a certain point, the stronger will be the concrete, but this does not mean that one should go too far in reducing the amount of water, nor is it practicable in actual construction to reduce it to a point that would give the maximum strength shown in laboratory tests. There is another factor that must be taken into account in construction and that is the workability of the mix. In general terms, the lowest amount of water should be used that will give a workable mix.

The strength falls off very quickly with the addition of a small amount of water; so much so that in a one-bag batch the addition of one pint of water more than is necessary to give a workable mix produces the same loss in strength as leaving out 2 or 3 pounds of cement. This does not mean that it is possible to use a very lean mix with a small amount of water and obtain as strong a concrete as a rich mix with the same amount of water. This is not true, because it will require a higher water-ratio to produce a workable mix with the lean mixture, thereby causing a loss in strength.

The proper consistency for concrete will vary according to the use to be made of it. If the concrete is used for roads a drier consistency is practicable than for building walls containing reinforcing bars. The use of mechanical tamping and finishing machines in concrete road construction has made it possible to use the drier consistency economically, but any method which reduces the water content, such as the use of the light roller, will produce similar results.

The very wet sloppy mixtures that are being used in building construction may seem economical from the contractors' point of view but they are certainly extremely wasteful from the designers' and owners' point of view, as from 50 to 60 per cent of the possible strength of the concrete is being thrown away.

It may not be possible to reduce the amount of the water to the ratio necessary to give the maximum strength, but it certainly can be cut down below the amount commonly used, and the additional strength thus gained taken advantage of in the design of concrete structures. The designing engineer figures on a compressive strength of 650 pounds per square inch and expects to get a factor of safety of three or at least two, but does not get it with the sloppy mixture often used. By cutting down the water to the proper ratio, a factor of safety of five or six can be secured, and the allowable unit stress raised.

It is not possible to give the exact amount of water required for any particular mixture of aggregates to give the greatest strength in the concrete, owing to the impossibility of determining what amount will produce a workable mix and also due to the varying moisture content of the aggregate. A few approximate quantities for different proportions of well graded aggregates up to $1\frac{1}{2}$ inch in size, may be given to form a basis for trial of the particular mixture at hand. A 1:2:4 mixture will require from 6 to $6\frac{1}{2}$ gallons of water

per sack of cement, a 1:2:3 mix, $5\frac{3}{4}$ to $6\frac{1}{4}$ gallons and a 1:$1\frac{1}{2}$:3 mix, $5\frac{1}{2}$ to 6 gallons.

Slump test. In order to have a simple method for determining the proper consistency in the field the slump test has been devised.

When this was first devised a metal cylinder 6 inches in diameter and 12 inches high was used, but now a frustum of a cone 4 inches at the top and 8 inches at the bottom and 12 inches high has been adopted as a standard. This change was made owing to the tendency of the cylinder to lift portions of the concrete when it is being taken off and the dropping of this concrete causes variable results. The cone once loosened does not again come in contact with the concrete and the results are much more uniform. This cone is filled with the concrete to be tested, which is carefully worked with a metal rod while it is being placed, the form is immediately lifted off, and the settlement or slump measured. The proper slump for a mixture to be used for a concrete road surface is from $\frac{1}{2}$ to 1 inch; for mass work, from 1 to $1\frac{1}{2}$ inch and for concrete to be used in building walls with reinforcing bars $1\frac{1}{2}$ to 2 inches.

Manipulation of ingredients. In considering the final step, the manipulation of the ingredients during the making of the concrete, careful studies have been made of each operation. Included in this phase are the curing or protecting of the concrete during the early hardening period, as this is one of the vital operations in the making of good concrete.

The time of mixing is a matter of importance in obtaining good concrete and one that vitally affects the output of the mixer and consequently the cost. Exhaustive tests made on concrete mixed in a batch mixer from 15 seconds to 10 minutes, show a rapid increase in strength for the first minute, after which the increase is less pronounced as the time of mixing increases.

This shows the necessity of mixing the concrete at least 60 seconds and not 20 to 40 seconds only, as is often done in road and street construction. There is no question as to the advisability of using a batch meter on the mixer, provided one can be found that cannot be tampered with, in order to avoid controversy over the time of mixing and to insure a full minute mix. When a mixer is manufactured that will not permit discharge until a certain number of revolutions has been made at a certain speed this problem will have been solved.

The revolutions per minute of the mixer within the limits of 12 to 25 revolutions per minute have but very little effect on the

strength of the concrete, so that a sufficiently wide variation for different machines is permitted. In making tests of the effect of revolutions per minute on concrete the total time was one minute in all cases, and all materials, including water, were placed in the drum before the time interval was counted.

The effect of pressure on concrete immediately after moulding is found to be due to the amount of water squeezed out, making a consequent reduction of the water ratio. Tests were made on concrete of the same proportions, by applying pressure from zero to 500 pounds per square inch. The water expelled was carefully collected and measured. It was found the strength increased quite materially with the higher pressures and this increased strength was almost directly proportional to the amount of water squeezed out. It is not surprising to find, then, that the duration of the pressure had no effect whatever on the strength of the concrete. Whether pressure was applied for a few minutes or for several hours the effect produced was exactly the same.

It is undoubtedly the squeezing out of the water and consequent reduction of water-ratio that produces the excellent results when the roller method of finishing concrete roads is used.

The time that can be allowed between the time of mixing and the time of placing has not as yet been made the subject of extensive tests at the laboratory. This knowledge is of value when considered in conjunction with central mixing plants, which are used with success in many places. The lapsed time is undoubtedly governed to a certain extent by the kind of cement used, by the temperature of the ingredients and by the temperature of the mixed concrete. In Illinois a limit of 40 minutes lapsed time is allowed but it is generally believed that the economical haul for the job will be the governing factor rather than the fixing of a time limit.

It is possible that some of our present ideas regarding this factor may be changed by the results of such a series of tests, but until such a time it would not be advisable to allow re-tempering of concrete that has been too long in transit, as the addition of water will no doubt result in a reduction in strength.

Protection. The proper protection of concrete during the early hardening period is a detail of construction that is only too often overlooked and many times only indifferently carried out.

The effect of proper curing conditions upon the ability of the concrete to withstand abrasion has been very strongly brought out by numerous tests in the laboratory. There is probably no method

of handling concrete that so affects its wearing ability, as that of providing proper protection while curing or hardening.

It is true that any and all of the factors that tend to produce strength in concrete also tend to increase its wearing qualities, nevertheless all of the tests show that, other factors being the same, the concrete which is properly protected will show much less wear than that which has been allowed to dry out too quickly. As an illustration of this the strength of a concrete of 1.25 consistency was about 1700 pounds per square inch when it was allowed to dry out in the air unprotected and exactly the same concrete stored in damp sand for 21 days gave a strength of about 4000 pounds per square inch and a correspondingly less wear under the rattler test.

One of the principal causes of the poor wearing resistance that we sometimes find in concrete floors is due to the practice of allowing them to dry out without proper protection during the hardening period.

Concrete floors under roof should be covered and kept moist just as outside roads and pavements are protected. Why throw away one half the life of a concrete floor by failing to observe this rule and holding back from using them for so short a period?

The essential requirements for proper hardening are warmth and the presence of moisture, especially the latter. The tests show a less increase in wearing resistance and strength after 21 days have elapsed and a constant rate of increase during this period. In deciding on the length of time that a pavement, or other structure, shall be kept covered and moist, it is simply a matter of deciding how much of the potential strength and wear resisting qualities it is desirable to throw away and reduce the 21 day period by that amount.

There are several methods of protecting concrete pavements during this period, the most effective of which is the ponding method and where the grades and other conditions will permit this method to be used, it will give the most lasting results. The protection of concrete structures other than pavements is very often either neglected altogether or at best only half carried out. Many times the leaving on of the forms is considered to be sufficient protection in itself, but this is not so.

The forms and all exposed surfaces should be kept thoroughly wet, or at least very moist continuously for not less than 14 days and whenever possible for 21 days or more.